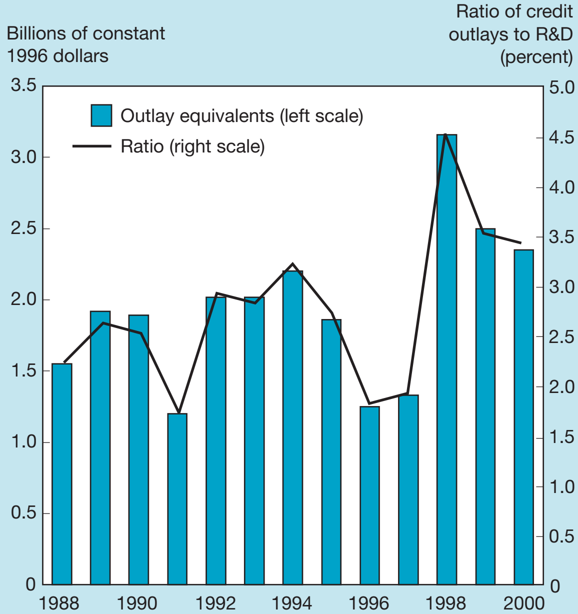
Figure 4-8.
Budgetary impact of Federal research and experimentation tax credit: FYs 1988–2000



NOTE: The ratio of credit outlays to R&D is the outlay equivalent cost of the tax credit divided by total Federal R&D outlays.

See appendix table 4-30. *Science & Engineering Indicators – 2002*

real terms. It then slowed to 4.4 percent between 1985 and 1990 and to 3.3 percent between 1990 and 1995 but rose to 8.2 percent over the 1995–2000 period.

As already discussed, most non-Federal R&D support is provided by industry. Of the 2000 non-Federal support total ($195 billion), 92.8 percent ($181 billion) was company funded. Industry's share of national R&D funding first surpassed that of the Federal Government in 1980, and it has remained higher ever since. From 1980 to 1985, industrial support for R&D, in real dollars, grew at an average annual rate of 7.7 percent. This growth was maintained through both the mild 1980 recession and the more severe 1982 recession. (See figure 4-1.) Key factors behind increases in industrial R&D included a growing concern with international competition, especially in high-technology industries; the increasing technological sophistication of products, processes, and services; and general growth in defense-related industries, such as electronics, aircraft, and missiles.

Between 1985 and 1994, growth in R&D funding from industry was slower, averaging only 3.1 percent per year in real terms. This slower growth in industrial R&D funding was only slightly greater than the real growth of the economy over the same period (in terms of real GDP), which was 2.8 percent. In contrast, from 1994 to 2000, non-Federal R&D support grew in real terms by 8.6 percent per year compared with 4.0 percent for the economy overall.

R&D funding from other non-Federal sectors, namely, academic and other nonprofit institutions and state and local governments, has been more consistent over time. It grew in real terms at average annual rates of 6.4 percent between 1980 and 1985, 8.5 percent between 1985 and 1990, 3.8 percent between 1990 and 1995, and 5.5 percent between 1995 and 2000. The level of $14.0 billion in funding in 2000 was 4.9 percent higher in real terms than its 1999 level of $13.0 billion. Most of these funds had been used for research performed within the academic sector.

R&D Performance in the United States

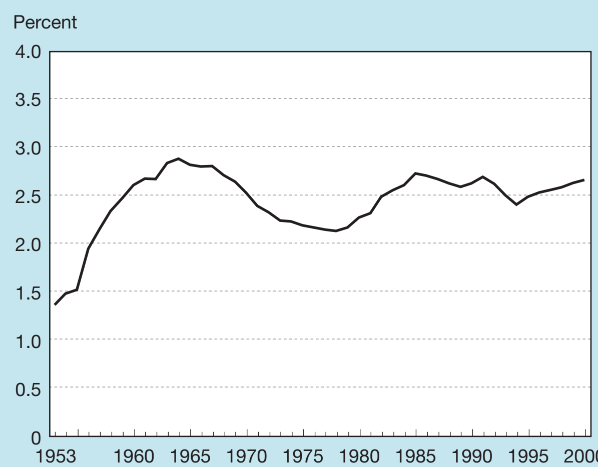
U.S. R&D/GDP Ratio

Growth in R&D expenditures should be examined in the context of the overall growth of the economy, because, as a part of the economy itself, R&D is influenced by many of the same factors. Furthermore, as mentioned earlier, the ratio of R&D expenditures to GDP may be interpreted as a measure of the nation's commitment to R&D relative to other endeavors.

A review of U.S. R&D expenditures as a percentage of GDP over time shows an initial low of 1.36 percent in 1953 (when the NSF data series began), rising to its highest peak of 2.88 percent in 1964, followed by a gradual decline to 2.12 percent in 1978. (See figure 4-9.) From that low in 1978, U.S. R&D expenditures again rose steadily to peak at 2.72 percent in 1985 and did not fall below 2.50 until 1993. In 1994, the rate dropped to 2.40, its lowest point since 1981. Starting in 1994, however, R&D/GDP has been on an upward trend as investments in R&D have outpaced growth of the general economy. As a result, the current ratio of 2.66 for 2000 is the highest the ratio has been since 1985.

The initial drop in the R&D/GDP ratio from its peak in 1964 largely reflects Federal cutbacks in defense and space R&D programs, although gains in energy R&D activities between 1975 and 1979 resulted in a relative stabilization of the ratio between

Figure 4-9.
Historical pattern of R&D as percentage of GDP: 1953–2000



See appendix tables 4-1 and 4-3.

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2.1 and 2.2 percent. Over the entire 1965–78 period, the annual percentage increase in real R&D was less than the annual percentage increase in real GDP. When real R&D spending decreased during that period, real GDP also fell, but at a lower rate.

The rise in R&D/GDP from 1978 to 1985 was due as much to a slowdown in GDP growth as it was to increased spending on R&D activities. For example, the 1980 and 1982 recessions resulted in a slight decline in real GDP, but there was no corresponding reduction in R&D spending. During previous recessions, changes in funding for R&D tended to match or exceed the adverse movements of the broader economic measures.

The share of defense-related R&D dropped from 31 percent in 1985 to 23 percent in 1991. Commensurate with this change was the sharp fall in the share of federally funded R&D, from 46 percent in 1985 to 37.8 percent in 1991. (See figure 4-4.) This decline in Federal funding was counterbalanced by increased non-Federal funding, as described earlier in the discussion of industrial trends. Indeed, since the late 1980s, practically all of the rise in the R&D/GDP ratio has resulted from gains in industrial R&D spending.

From 1991 to 1994, the R&D/GDP ratio declined from 2.69 to 2.40. Since then, however, it has risen steadily. Between 1994 and 2000, the R&D supported by industry grew in real terms by 8.6 percent annually, whereas real GDP grew by 4.0 percent, largely explaining the rise in the R&D/GDP ratio to 2.66 in 2000. From 1992 to 2000, the ratio of research alone to GDP has remained at 1.0 percent, while the ratio of development to GDP has varied between 1.5 and 1.6 percent. Within the industrial sector, however, development plays a greater role. In 1999, for example, the ratio of research performance to net sales in industry was 0.8 percent, while the ratio of development to net sales was 2.0 percent.

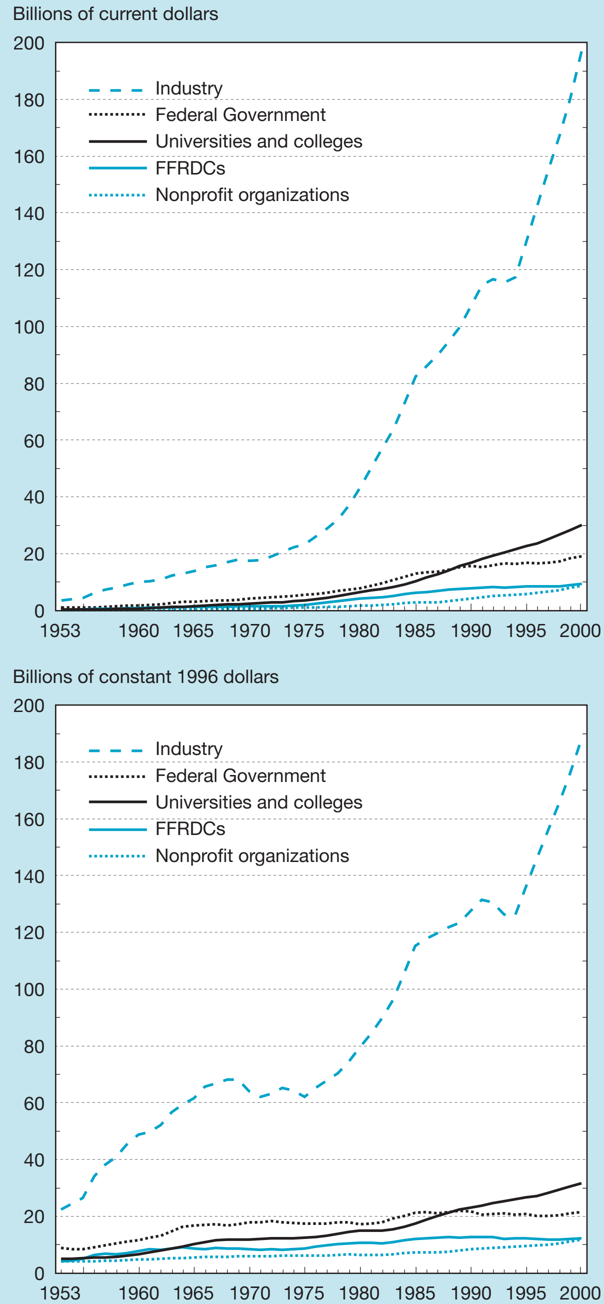
Rates of Growth Among Sectors

The sectoral shares of U.S. R&D performance have shifted significantly since the early 1980s. (See figure 4-10 for levels of expenditure.) In 1980, industry (including industry-administered FFRDCs) performed 70.3 percent of the nation's R&D; the academic sector (including academically administered FFRDCs) accounted for 13.9 percent; the Federal Government accounted for 12.4 percent; and the nonprofit sector (including nonprofit-administered FFRDCs) accounted for 3.3 percent. Industry's defense-related R&D efforts accelerated in the early 1980s, and its share of performance total rose to 73.4 percent in 1985.

From 1985 to 1994, R&D performance grew by only 1.4 percent per year in real terms for all sectors combined. This growth was not evenly balanced across performing sectors, however. R&D performance at universities and colleges (including their FFRDCs) grew by 4.4 percent per year in real terms compared with only 1.0 percent growth for industry (including their FFRDCs), a decline of 0.5 percent per year for Federal intramural performance and growth of 4.0 percent per year for nonprofit organizations (including their FFRDCs).

The 1994–2000 period witnessed dramatic changes in these growth rates. Total R&D performance, in real terms, averaged 5.8 percent growth per year, which was substantially higher than in the earlier sluggish period. Yet, R&D performance at universities and colleges (including their FFRDCs) grew by only 3.1 percent per year in real terms. Industry (including their FFRDCs) grew at a remarkable rate of 7.0 percent in real terms. Federal intramural performance increased by 0.8 percent per year in real terms. Finally, nonprofit organizations (including

Figure 4-10.
National R&D performance, by type of performer: 1953–2000



FFRDCs = Federally Funded Research and Development Centers

See appendix tables 4-3 and 4-4.

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their FFRDCs), according to current estimates, increased their R&D by 5.3 percent per year in real terms over the same six-year period. According to preliminary estimates, these shifts in growth have led, in 2000, to academia (including FFRDCs) representing 13.6 percent of total U.S. R&D performance; Federal intramural activities, 7.2 percent; other nonprofit organizations (including FFRDCs), 3.6 percent; and private industry (including FFRDCs), 75.6 percent. (For level of expenditures in 2000, see text table 4-1.)

Federal R&D Performance

The Federal Government performed $19.1 billion of total U.S. R&D in calendar year 2000, a 2.3 percent rise in real terms from its 1999 level of $18.3 billion. Among the individual agencies, DOD has continued to perform the most intramural R&D; in fact, in FY 2001 it performed more than twice the R&D of the second largest R&D-performing agency, HHS (whose intramural R&D is performed primarily by NIH). (See text table 4-3.) However, DOD's intramural R&D performance has grown by less than 1 percent per year in real terms since FY 1980, reaching a level of $8.6 billion in FY 2001. Furthermore, an undetermined amount of DOD's intramural R&D ultimately appears to be contracted out to other extramural performers. NASA's intramural R&D has grown by 1.4 percent per year in real terms since 1980, to $2.5 billion in FY 2001, and HHS intramural performance rose by 4.0 percent to $3.7 billion. Together, these three agencies account for 76.2 percent of the total ($19.4 billion) Federal intramural R&D in FY 2001.

Total R&D performed by industrial, academic, and nonprofit FFRDCs reached $9.3 billion in calendar year 2000, which is essentially the same as its level of $9.0 billion in 1999 after adjusting for inflation. R&D at FFRDCs in 2000 represented 3.5 percent of the national R&D effort, most of which ($5.8 billion in 2000) was accounted for by university- and college-administered FFRDCs.

R&D in Nonprofit Organizations

A recent NSF survey has led to upward revisions in R&D performance estimates for the nonprofit sector (NSF 2001d). Based on a survey of FY 1996 and FY 1997 R&D at nonprofit organizations and on other available data for the past three years, R&D performance by nonprofit organizations is expected to reach $8.8 billion in 2000, reflecting an average annual growth of 5.5 percent, in real terms, since 1990. Such growth, however, varies considerably by source of funding. The average annual real growth in nonprofit intramural R&D over the same period was 8.0 percent for nonprofit R&D supported by nonprofit organizations themselves, 7.1 percent for nonprofit R&D supported by industry, and 3.5 percent for nonprofit R&D supported by the Federal Government.

Like the Federal Government, nonprofit organizations in recent decades have focused largely on medical and health

Text table 4-6.
Intramural R&D performance at nonprofit organizations, by type of organization and S&E field: FYs 1973 and 1997
(Millions of dollars)

Organization type	Total	Life sciences: Biological sciences	Life sciences: Agricultural sciences	Life sciences: Medical and and health sciences	Psychology	Environmental and earth sciences	Physical sciences	Mathematics and computer sciences	Engineering	Social sciences	Other sciences
1973											
Total	786	162	167	26	30	19	72	37	136	130	5
Research institutes	487	104	44	11	18	9	50	34	98	113	5
Hospitals	163	40	98	6	5	0	5	2	2	6	—
Professional or technical societies	62	5	17	4	—	5	13	—	15	2	0
Private foundations	14	5	1	—	—	2	2	0	0	2	0
Science exhibitors	8	4	—	0	—	2	1	0	0	2	0
Trade associations	26	2	0	0	0	1	2	—	20	1	0
Other nonprofit organizations	26	3	7	5	6	0	0	—	—	4	0
1997											
Total	7,349	854	22	4,413	70	232	255	269	490	325	419
Research institutes	4,839	794	11	2,618	65	97	147	263	458	305	83
Hospitals	1,428	20	0	1,408	—	0	0	1	0	0	0
University-affiliated hospitals	464	0	0	463	0	0	0	1	0	0	0
Other voluntary nonprofit hospitals	965	20	0	945	—	0	0	0	0	0	0
Private foundations	458	28	11	386	4	2	11	3	—	10	2
Other nonprofit organizations[a]	624	13	1	2	0	133	97	2	32	10	334

— = Less than $0.5 million

[a]Other nonprofit organizations include professional and technical societies, academies of science or engineering, science exhibitors, academic consortia, industrial consortia, and trade associations.

NOTE: Details may not add to totals because of rounding.

SOURCES: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *R&D Activities of Independent Nonprofit Institutions* (Washington, DC, 1973); and NSF/SRS, *Research and Development Funding and Performance by Nonprofit Organizations: Fiscal Years 1996 and 1997,* Early Release Tables. Available at: <http://www.nsf.gov/sbe/srs/srs01411/start.htm>.

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sciences. (See text table 4-6.) In 1973, only 3.3 percent of all R&D performed by nonprofit organizations was in medical and health sciences, but this share rose dramatically to 60 percent by 1997. In contrast, the agricultural sciences share of intramural nonprofit R&D fell from 21.3 percent in 1973 to 0.3 percent in 1997.

Recent Growth in Industrial R&D, by Sector, Firm Size, and R&D Intensity

R&D performance by private industry reached $199.9 billion in 2000, including $2.6 billion spent by FFRDCs administered by industrial firms. This total represents a 7.1 percent real increase over the 1999 level of $82.8 billion, which, in turn, reflects a smaller, although still noteworthy, real gain of 6.5 percent over 1998. In 2000, R&D performed by industry that was not federally financed rose 8.6 percent in real terms above the 1999 level. Overall, private companies (excluding industry-administered FFRDCs) funded 90.0 percent ($177.6 billion) of their 2000 R&D performance, with the Federal Government funding nearly all the rest ($19.6 billion, or 10 percent of the total).

In recent times, the greatest share of R&D in the United States has been performed by private industry through private industry's own funds.[17] This component of U.S. R&D has grown in importance, from 44 percent of total R&D in 1953, to 49 percent in 1980, to 55 percent in 1990, and 68 percent in 2000. The underlying causes for industry's growing share of R&D financing are complex. In part, the growth may be due to changes in Federal support in areas such as defense and space exploration. Other factors include S&E success stories in specific fields, such as information technology (IT) and biotechnology, in which industry plays a dominant role.

R&D in Manufacturing Versus Nonmanufacturing Industries

Until the 1980s, little attention was paid to R&D conducted by nonmanufacturing companies largely because service-sector R&D activity was negligible compared with the R&D operations of companies classified in manufacturing industries. Before 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total (including industrial FFRDCs), but by 1999 (the most current year for data on industrial sectors), it had reached 36.0 percent. In 1999, nonmanufacturing firms' R&D performance totaled $65.9 billion ($60.4 billion in funds provided by companies and other non-Federal sources and $5.5 billion in Federal support).

Beginning with the 1999 cycle, statistics from NSF's Survey of Industrial R&D have been published using the North American Industrial Classification System (NAICS). (See text table 4-7.) The development of NAICS has been a joint effort of statistical agencies in Canada, Mexico, and the United States. The system replaces the standard industrial classification (SIC) (1980) of Canada, the Mexican Classification of Activities and Products (1994), and SIC (1987) of the United States. NAICS was designed to provide a production-oriented system under which economic units with similar production processes are classified in the same industry. NAICS was developed with special attention to classifications for new and emerging industries, service industries, and industries that produce advanced technologies. NAICS eases comparability of information about the economies of the three North American countries and also increases comparability with the two-digit level of the United Nations International Standard Industrial Classification system (ISIC Revision 3).

Among manufacturers, the new computer and electronic products classification (NAICS 334) includes makers of computers and peripherals, semiconductors, and navigational and electromedical instruments. Among nonmanufacturing industries are information (NAICS 51) and professional, scientific, and technical services (NAICS 54). Information includes publishing (both paper and electronic), broadcasting, and telecommunications. Professional, scientific, and technical services include a variety of industries. Of specific importance for the survey are engineering and scientific R&D services (NSF 2001e).

Following these recent changes in classification, much of the historical data on R&D that had been subdivided according to the previous industrial categories cannot be reclassified into the current industrial categories. As a result, some of trends in the data by industrial category can no longer be observed after 1998 and must be started again, according to different groupings, in 1999. On the other hand, general patterns of change among major sectors are still identifiable. The most striking change in industrial R&D performance during the past two decades is the nonmanufacturing sector's increased prominence.

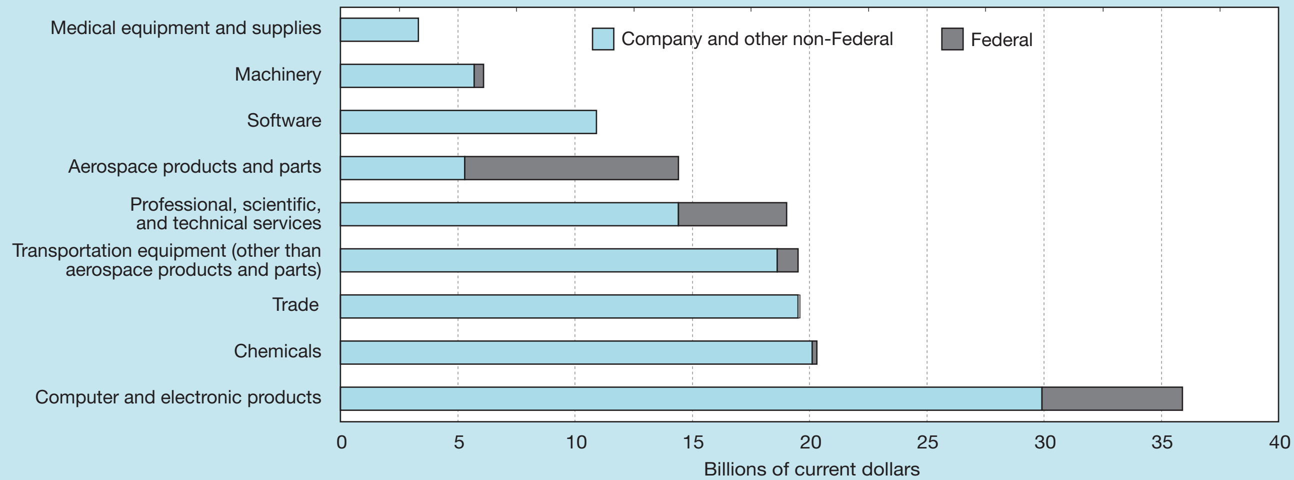
In 1999, the largest nonmanufacturing industry in the performance of R&D was trade (as it is classified in NAICS), which accounted for 10.7 percent of all industrial R&D performance. This was followed closely by professional, scientific, and technical services, accounting for another 10.4 percent of the total, then information, accounting for 8.4 percent.

Within the manufacturing industrial sector (including industry-administered FFRDCs associated with manufacturing), three subsectors dominate: computer and electronic products, transportation equipment, and chemicals. (See figure 4-11 and text table 4-7.) Under the new NAICS system of classification, the computer and electronic products sector accounted for the largest amount of R&D performed in 1999 among all industrial sectors—$35.9 billion. It accounted for 19.7 percent of all industrial R&D (including industry FFRDCs), as well as 14.7 percent of the entire nation's R&D, performed in 1999. Consequently, it exceeded the total amount of R&D performed in 1999 by all universities and colleges and their administered FFRDCs combined (which is only $34.1 billion). For this sector, industrial firms provided $29.9 billion in R&D support; the Federal Government funded the remainder.

Transportation equipment was a close second among the manufacturing sectors in R&D performed in 1999 with $34 billion in R&D, representing 18.6 percent of all industrial

[17] Some of this funding is supported through venture capital investments. For a discussion of the relationship between venture capital and R&D expenditures, see chapter 6.

Figure 4-11.
Industrial R&D performance for selected industries, by source of funds: 1999



See appendix tables 4-31, 4-32, and 4-33.

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R&D (including R&D by industry-administered FFRDCs). Of these expenditures, 29.6 percent was federally funded, primarily for R&D on aerospace products (planes, missiles, and space vehicles). In addition to aerospace products, the sector includes a variety of other forms of transportation equipment, such as motor vehicles, ships, military armored vehicles, locomotives, and smaller vehicles like motorcycles, bicycles, and snowmobiles (U.S. OMB 1997).

Ranking third in R&D is chemicals, with $20.2 billion in 1999, for which less than 1 percent was federally funded. This sector includes the subsectors pharmaceuticals and medicines (61.0 percent of non-Federal R&D funding in the chemical sector); basic chemicals (13.2 percent); resin, synthetic rubber, fibers, and filament (11.1 percent); and other chemicals (14.7 percent).

Although a great deal of R&D in the United States is related in some way to health care services, companies specifically categorized in the health care services sector accounted for only 0.4 percent of all industrial R&D and for only 1.0 percent of all R&D by nonmanufacturing companies. These results illustrate that R&D data disaggregated according to industrial categories (including the distinction between manufacturing and nonmanufacturing industries) may not always reflect the relative proportions of R&D devoted to particular types of scientific or engineering objectives, or to particular fields of science or engineering.[18] The section "Cross-Sector Field-of-Science Classification Analysis" compensates to some extent for this limitation in the data by providing R&D expenditure levels associated with the broadly defined fields of life sciences and chemistry.

As a case in point, firms that perform R&D under contract to other firms are, by definition, in the service sector because the R&D they perform is, in fact, their "product," which is a service as opposed to manufactured goods. However, they often perform R&D under contract with a manufacturer, implying that those same R&D activities would have been classified as R&D in manufacturing if the same research firm were a subsidiary of the manufacturer. This is counterintuitive in that it implies that whether R&D is in manufacturing or in services is determined, in part, not by physical aspects of the R&D actions themselves but by the labels that have been placed on the firms that perform the R&D. Consequently, a growth in measured R&D in services may, in part, "reflect a more general pattern of industry's increasing reliance on outsourcing and contract R&D" (Jankowski 2001b).

R&D Spending by U.S. Corporations

In 1998, the top 20 U.S. corporations in R&D expenditures spent $54.0 billion on R&D. General Motors reported the most R&D in 1998 with $7.9 billion, followed by another company in the motor vehicle sector, Ford Motor Company, with $6.3 billion. (See text table 4-8.) The rest of the list is dominated by computers, electronic equipment, and software companies, and by pharmaceutical corporations.

Between 1996 and 1998, the total number of publicly held U.S. corporations reporting R&D spending fell from 3,256 to 3,028, although some of this decline is attributable to mergers among existing firms. The decline in the number of firms was not uniform across industrial sectors. For example, the aircraft, guided missiles, and space vehicles sector, which is characterized by relatively large corporations, included exactly 21 corporations in each of the three years. Similarly, the motor vehicles and surface transportation sector went down in number by only 1, from 71 to 70 corporations. This was due to the acquisition of Chrysler Corporation by the German firm Daimler-Benz, which removed Chrysler from the list of U.S. corporations performing R&D (although the R&D

[18]For a more detailed discussion of limitations in the interpretation of R&D levels by industrial categorization, see Payson (2000).

Text table 4-7.
Industrial R&D performance, by industry and source of funding: 1999
(Millions of dollars)

Industry	NAICS code	Total R&D	Company funded	Federally funded	Percent federally funded
All industries	21–23, 31–33, 42, 44–81	182,823	160,288	22,535	12.3
Manufacturing	31–33	116,921	99,865	17,055	14.6
Food	311	1,132	1,132	0	0.0
Beverage and tobacco products	312	D	D	0	NA
Textiles, apparel, and leather	313–16	334	334	0	0.0
Wood products	321	70	70	0	0.0
Paper, printing, and support activities	322, 323	D	2,474	D	NA
Petroleum and coal products	324	615	D	D	NA
Chemicals	325	20,246	20,051	194	1.0
Basic chemicals	3251	2,746	2,648	98	3.6
Resin, synthetic rubber, fibers, and filament	3252	D	2,216	D	NA
Pharmaceuticals and medicines	3254	D	12,236	D	NA
Other chemicals	325 minus (3251–52, 3254)	D	2,951	D	NA
Plastics and rubber products	326	1,785	1,785	0	0.0
Nonmetallic mineral products	327	D	595	D	NA
Primary metals	331	470	457	12	2.6
Fabricated metal products	332	1,655	1,608	46	2.8
Machinery	333	6,057	5,658	399	6.6
Computer and electronic products	334	35,932	29,939	5,993	16.7
Computers and peripheral equipment	3341	D	4,126	D	NA
Communications equipment	3342	6,003	5,797	206	3.4
Semiconductor and other electronic components	3344	10,701	10,624	77	0.7
Navigational, measuring, electromedical, and control instruments	3345	14,337	8,632	5,705	39.8
Other computer and electronic products	334 minus (3341–42, 3344–45)	D	760	D	NA
Electrical equipment, appliances, and components	335	D	3,820	D	NA
Transportation equipment	336	33,965	23,928	10,037	29.6
Motor vehicles, trailers, and parts	3361–63	D	17,987	D	NA
Aerospace products and parts	3364	14,425	5,309	9,117	63.2
Other transportation equipment	336 minus (3361–64)	D	632	D	NA
Furniture and related products	337	248	248	0	0.0
Miscellaneous manufacturing	339	3,851	3,825	26	0.7
Medical equipment and supplies	3391	D	3,251	D	NA
Other miscellaneous manufacturing	339 minus 3391	D	574	D	NA
Small manufacturing companies[a]	<50 employees	3,019	2,950	69	2.3
Nonmanufacturing	21–23, 42, 44–81	65,902	60,423	5,479	8.3
Mining, extraction, and support activities	21	D	2,352	D	NA
Utilities	22	142	126	17	12.0
Construction	23	691	690	2	0.3
Trade	42, 44, 45	19,616	19,521	95	0.5
Transportation and warehousing	48, 49	460	460	0	0.0
Information	51	15,389	14,892	497	3.2
Publishing	511	11,302	11,253	49	0.4
Newspaper, periodical, book, and database	5111	371	371	0	0.0
Software	5112	10,931	10,882	49	0.4
Broadcasting and telecommunications	513	D	1,393	D	NA
Other information	51 minus (511, 513)	D	2,246	D	NA
Finance, insurance, and real estate	52, 53	D	1,570	D	NA
Professional, scientific, and technical services	54	18,994	14,379	4,615	24.3
Architectural, engineering, and related services	5413	3,580	2,402	1,177	32.9
Computer systems design and related services	5415	D	3,989	D	NA
Scientific R&D services	5417	10,470	7,413	3,057	29.2
Other professional, scientific, and technical services	54 minus (5413, 5415, 5417)	D	575	D	NA
Management of companies and enterprises	55	D	72	D	NA
Health care services	621–23	642	631	10	1.6
Other nonmanufacturing	56, 61, 624, 71, 72, 81	D	752	D	NA
Small nonmanufacturing companies[a]	<15 employees	5,203	4,977	227	4.3

NAICS = North American Industry Classification System; D = data withheld to avoid disclosing operations of individual companies; NA = not available

[a]The frame from which the statistical sample was selected was divided into two partitions based on total company employment. In the manufacturing sector, companies with employment of 50 or more were included in the large company partition. In the nonmanufacturing sector, companies with employment of 15 or more were included in the large company partition. Companies in the respective sectors with employment below these values, but with at least 5 employees, were included in the small company partition. The purpose of partitioning the sample this way was to reduce the variability in industry estimates largely attributed to the random year-to-year selection of small companies by industry and the high sampling weights that sometimes were assigned to them. Because of this, detailed industry statistics were possible only from the large company partition. Statistics from the small company partition are shown separately and are included in manufacturing, nonmanufacturing, and all industries totals.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999,* Early Release Tables (Arlington, VA, 2001)

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Text table 4-8.
Top 20 R&D spending corporations: 1998

R&D rank				R&D (billions of dollars)			Percent change from	Sector	
1998	1997	1996	Corporation	1998	1997	1996	1996 to 1998	Major	Detailed
1	1	1	General Motors	7.900	8.200	8.900	–11.2	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
2	2	2	Ford Motor Co.	6.300	6.327	6.821	–7.6	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
3	3	3	Intl. Business Machines	4.466	4.307	3.934	13.5	Information and electronics	Multiple and miscellaneous computer and data processing services
4	4	7	Lucent Technologies	3.678	3.101	1.838	100.1	Information and electronics	Modems and other wired telephone equipment
5	5	4	Hewlett-Packard	3.355	3.078	2.718	23.4	Information and electronics	Electronic computers and computer terminals
6	6	5	Motorola	2.893	2.748	2.394	20.8	Information and electronics	Radio, TV, cell phone, and satellite communications equipment
7	7	8	Intel	2.509	2.347	1.808	38.8	Information and electronics	Electronic components (e.g., semiconductors, coils)
8	10	11	Microsoft	2.502	1.925	1.432	74.7	Information and electronics	Prepackaged software
9	9	9	Pfizer	2.279	1.928	1.684	35.3	Medical substances and devices	Drugs: pharmaceutical preparations
10	8	6	Johnson & Johnson	2.269	2.140	1.905	19.1	Medical substances and devices	Drugs: pharmaceutical preparations
11	11	18	Boeing	1.895	1.924	1.200	57.9	Aircraft, guided missiles, and space vehicles	Aircraft, guided missiles, and space vehicles
12	12	10	Merck & Company	1.821	1.684	1.487	22.4	Medical substances and devices	Drugs: pharmaceutical preparations
13	16	19	Eli Lilly & Company	1.739	1.382	1.190	46.2	Medical substances and devices	Drugs: pharmaceutical preparations
14	13	12	American Home Products	1.655	1.558	1.429	15.8	Medical substances and devices	Drugs: pharmaceutical preparations
15	15	14	Bristol Myers Squibb	1.577	1.385	1.276	23.6	Medical substances and devices	Drugs: pharmaceutical preparations
16	18	16	Procter & Gamble	1.546	1.282	1.221	26.6	Chemicals	Other chemical (e.g., soaps, ink, paints, fertilizers, explosives)
17	14	13	General Electric	1.537	1.480	1.421	8.2	Machinery and electrical equipment	Electrical equipment (industrial and household)
18	NA	NA	Delphi Automotive System	1.400	NA	NA	NA	Motor vehicles and surface transportation	Motor vehicles and motor vehicle equipment
19	31	50	Compaq	1.353	0.817	0.407	232.4	Information and electronics	Electronic computers and computer terminals
20	20	20	United Technologies	1.315	1.187	1.122	17.2	Aircraft, guided missiles, and space vehicles	Aircraft, guided missiles, and space vehicles

NA = not available

SOURCE: Standard & Poor's Compustat (Englewood, CO).

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it performs within the United States is still collected by NSF's industrial R&D survey and included in this chapter's data on U.S. industrial R&D performance).[19] Chrysler was ranked number 12 in U.S. corporations' 1997 R&D spending. In contrast, between 1996 and 1998, the number of R&D-performing corporations fell from 1,477 to 1,382 in the information and electronics sector, from 629 to 566 in the medical substances and devices sector, and from 422 to 386 in the basic industries and materials sector (Shepherd and Payson 2001).

Industrial R&D and Firm Size

Industrial manufacturing R&D performers are typically quite different from industrial nonmanufacturing R&D performers; nonmanufacturing R&D performers tend to be smaller firms. (See text table 4-9.) Approximately 39,000 firms in the United States performed R&D in 1999; of these, 54 percent were in the nonmanufacturing sector. Yet, manufacturers account for 64 percent of total industry R&D performance (including federally funded industry performance). As a share of the nation's GDP, on the other hand, manufacturing accounts for less than 20 percent. The main reason for continued dominance in R&D performance is that among manufacturing firms, the largest in terms of number of employees tend to perform a relatively large amount of R&D. Among small R&D-performing firms (fewer than 500 employees) in both the manufacturing and nonmanufacturing sectors, those in the nonmanufacturing sector tend to conduct twice as much R&D per firm as those in the manufacturing sector. However, among large R&D-performing firms (more than 25,000 employees) in both sectors, those in the manufacturing firms tend to conduct more than 10 times as much R&D per firm as those in the nonmanufacturing sector.

Although R&D tends to be performed by large firms in the manufacturing sector and small firms in the nonmanufacturing sector, within each sector there is consider-

[19]The corporate R&D data were obtained from a source that differs from the NSF *Survey of Industrial Research and Development*; namely, from the *U.S. Corporate R&D* database (see Shepherd and Payson 2001). Consequently, the definition of R&D in this case is not equivalent to that of the NSF industry R&D survey, as indicated in this example about the Chrysler Corporation.

Text table 4-9.
Total funds for industry R&D performance and number of R&D-performing companies in manufacturing and nonmanufacturing industries, by size of company: 1999

Size of company (number of employees)	Total	Manufacturing	Nonmanufacturing
	Funds for industrial R&D (millions of dollars)		
Total	182,823	116,921	65,902
5–25	7,004	738	6,265
25–49	4,750	791	3,959
50–99	7,225	2,183	5,042
100–249	7,213	2,623	4,591
250–499	7,892	2,190	5,701
500–999	7,032	3,763	3,269
1,000–4,999	24,840	15,561	9,278
5,000–9,999	16,376	10,893	5,483
10,000–24,999	24,922	18,014	6,908
25,000 or more	75,569	60,163	15,406
	Number of R&D-performing companies		
Total	39,005	18,059	20,946
5–25	18,355	5,750	12,606
25–49	6,749	3,707	3,042
50–99	5,102	2,644	2,457
100–249	4,083	2,840	1,243
250–499	1,788	975	813
500–999	1,118	890	228
1,000–4,999	1,157	865	292
5,000–9,999	288	194	94
10,000–24,999	198	129	69
25,000 or more	167	65	102

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999,* Early Release Tables (Arlington, VA, 2001

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able variation, depending on the type of industry. R&D tends to be conducted primarily by large firms in several industrial sectors: aircraft and missiles, electrical equipment, professional and scientific instruments, transportation equipment (not including aircraft and missiles), and transportation and utilities (which are in the nonmanufacturing sector). On the other hand, in these same sectors much of the economic activity is carried out by large firms to begin with, so the observation that most of the R&D in these sectors is also conducted by large firms is not surprising.

R&D Intensity

In addition to absolute levels of, and changes in, R&D expenditures, another key indicator of the health of industrial S&T is R&D intensity. R&D is similar to sales, marketing, and general management expenses in that it is discretionary, i.e., a nondirect revenue-producing item that can be trimmed when profits are falling. There seems to be considerable evidence, however, that R&D enjoys a high degree of immunity from belt-tightening endeavors, even when the economy is faltering, because of its crucial role in laying the foundation for future growth and prosperity. Nevertheless, whether industry devotes the right amount of economic resources to R&D has remained an open question. See sidebar, "Does Industry Underinvest in R&D?"

There are numerous ways to measure R&D intensity; the one used most frequently is the ratio of R&D funds to net sales.[20] This statistic provides a way to gauge the relative importance of R&D across industries and firms in the same industry. The industrial sectors with the highest R&D intensities in 1999 were scientific R&D services (32.1 percent), software (16.7 percent), communications equipment (11.6 percent), and computer systems design and related services (11.0 percent). Those with the lowest R&D intensities (less than 0.5 percent) were food, primary metals, broadcasting and telecommunications, and utilities. (See text table 4-10.) For all industries combined, the ratio of R&D to sales was 2.7 percent in 1999.

[20]Another measure of R&D intensity is the ratio of R&D to "value added" (which is sales *minus* the cost of materials). Value added is often used in studies of productivity analysis because it allows analysts to focus on the economic output attributable to the specific industrial sector in question by subtracting materials produced in other sectors. For a discussion of the connection between R&D intensity and technological progress, see, for example, Nelson (1988).

Does Industry Underinvest in R&D?

In a recent report by the National Institute for Standards and Technology (Tassey 1999), the author suggests that private industry may be underinvesting in R&D for the following reasons:

- ♦ **The riskiness of technology** must be factored in, not only in terms of achieving a technological advance but also in acquiring the ability to market it first. For example, if one firm initiates the research and makes the important discoveries but another firm is able to market the new technology first, then the firm that made the discovery would not recover its costs for R&D. Consequently, even though the economic returns to the second firm in this case would be very high, as would be the economic returns to society, the firm that initiated the effort may have good reason to be skeptical about its expected gains and therefore may be reluctant to initiate the work.
- ♦ **Spillovers from the technology** to other industries and to consumers, such as lower prices ("price spillovers") and increased general knowledge ("knowledge spillovers") may bring many benefits to the economy as a whole, independent of the returns to the firm that performs the R&D. As Tassey notes, "To the extent that rates of return fall below the private hurdle rate, investment by potential innovators will not occur."
- ♦ **Inefficiencies resulting from market structures,** in which firms may face high costs of achieving comparability when they are competing against each other in the development of technological infrastructure. For example, software developers are constrained, not only by the immediate development task at hand but also in having to ensure that the new software they develop is compatible with software and operating systems that other firms may be developing simultaneously. Here, greater efforts undertaken by industry or government to encourage standardization of emerging technologies would likely lead to higher returns to R&D.
- ♦ **Narrow corporate strategies.** According to Tassey, corporate strategies "often are narrower in scope than a new technology's market potential." In other words, companies in one line of business may not realize that the technological advances they make may have beneficial uses in other lines of business.* Thus, broader-based strategies that extend beyond a firm's immediate line of products would yield greater returns to R&D.
- ♦ **Large-scale technological infrastructure needs**. Like the Internet, technological infrastructure often yields high returns to individual companies and to the overall economy but often requires substantial levels of investment before any benefits can be realized. This argument is similar to the public-goods argument: for some large-scale R&D projects, funds from either government or an organized collaboration of industry participants may be necessary for the project to achieve the critical mass it needs to be successful. Once it is successful, however, high returns on the R&D invested might be realized.

Among NIST's general goals in addressing these issues is to encourage a "more analytically based and data-driven R&D policy."

*Levitt (1975) referred to this kind of problem as "marketing myopia."
SOURCE: Tassey (1999).

Performance by Geographic Location, Character of Work, and Field of Science

R&D by Geographic Location

The latest data available on the state distribution of R&D performance are for 1999. These data cover R&D performance by industry, academia, and Federal agencies, along with the federally funded R&D activities of nonprofit institutions.[21] In 1999, total R&D expenditures in the United States were $244.1 billion, of which $231.8 billion could be attributed to expenditures within individual states, with the remainder falling under an undistributed, "other/unknown" category. (See appendix tables 4-21 and 4-22.) The statistics and discussion below refer to state R&D levels in relation to the distributed total of $231.8 billion.

R&D is substantially concentrated in a small number of states. In 1999, California had the highest level of R&D performed within its borders—$48.0 billion—representing approximately one-fifth of the $231.8 billion U.S. total. The six states with the highest levels of R&D performance, California, Michigan, New York, Texas, Massachusetts, and Pennsylvania (in descending order), accounted for approximately one-half of the entire national effort. (See text table 4-11.) The top 10 states (the six above-mentioned states plus New Jersey, Illinois, Washington, and Maryland) accounted for approximately two-thirds of the national effort. (See appendix table 4-23.) California's R&D performance was 2.5 times as large as the R&D performance of the second highest state, Michigan, at $18.8 billion. After Michigan, ranking third was New York, with $14.1 billion, and the lowest of the top 10 states, Maryland, had $8.1 billion in R&D. The 20 highest ranking states in R&D expenditures accounted for 86.0 percent of the U.S. total; the lowest 20 states accounted for 4.5 percent.

[21]For historical data see appendix table 4-22. The state data on R&D contain 52 records: the 50 states; the District of Columbia and "other/unknown," which accounts for R&D in Puerto Rico and other nonstate U.S. regions; and R&D for which the particular state was not known. Approximately two-thirds of the R&D that could not be associated with a particular state is R&D performed by the nonprofit sector.

Text table 4-10.
Company and other (non-Federal) R&D funds as percentage of net sales in R&D-performing companies for selected industries: 1999

Industry	R&D as a percentage of sales
All industries	2.7
Manufacturing	3.2
Communications equipment	11.6
Pharmaceuticals and medicines	10.5
Navigational, measuring, electromedical, and control instruments	9.1
Semiconductor and other electronic components	8.3
Medical equipment and supplies	7.7
Computers and peripheral equipment	6.4
Resin, synthetic rubber, fibers, and filament	4.2
Machinery	3.3
Other chemicals	3.2
Aerospace products and parts	3.2
Motor vehicles, trailers, and parts	2.9
Electrical equipment, appliances, and components	2.3
Basic chemicals	2.0
Plastics and rubber products	1.9
Nonmetallic mineral products	1.5
Paper, printing and support activities	1.4
Fabricated metal products	1.4
Textiles, apparel, and leather	0.7
Furniture and related products	0.7
Wood products	0.5
Food	0.4
Primary metals	0.4
Nonmanufacturing	2.2
Scientific R&D services	32.1
Software	16.7
Computer systems design and related services	11.0
Architectural, engineering, and related services	6.8
Health care services	6.4
Management of companies and enterprises	5.7
Trade	5.5
Construction	3.1
Newspaper, periodical, book, and database information	2.0
Mining, extraction, and support activities	1.9
Finance, insurance, and real estate	0.5
Transportation and warehousing	0.5
Broadcasting and telecommunications	0.4
Utilities	0.1

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Research and Development in Industry: 1999,* Early Release Tables (Arlington, VA, 2001)

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States vary widely in the size of their economies because of differences in population, land area, infrastructure, natural resources, and history. Consequently, variation in the R&D expenditure levels of states may simply reflect differences in their economic size or the nature of their R&D efforts. A basic way of controlling for this "size effect" is to measure each state's R&D level as a proportion of its gross state product (GSP). (See appendix table 4-23.) Like the term used in reference to the ratio of industrial R&D to sales, the proportion of a state's GSP devoted to R&D is referred to as R&D "intensity" or "concentration." Overall, the nation's total R&D to GDP ratio in 1999 was 2.63 percent. The top 10 rankings for R&D intensity were, in descending order, New Mexico (6.4 percent), Michigan (6.1 percent), Rhode Island (5.1 percent), Massachusetts (4.6 percent), Maryland (4.6 percent), the District of Columbia (4.5 percent), Washington (4.0 percent), California (3.9 percent), Delaware (3.9 percent), and Idaho (3.8 percent).

States have always varied in terms of the levels and types of industrial operations they contain. Thus, they also vary in the levels of R&D they contain by industrial sector. One measure of such variation among states is the extent to which their industrial R&D is in the manufacturing sector as opposed to the nonmanufacturing sector. Among the top 10 states in 1999 in industrial R&D performance, California, Massachusetts, Ohio, Texas, and Washington all had relatively low shares of R&D in the manufacturing sector (less than 64 percent, which was the national average). Higher levels of R&D in manufacturing, as a percentage of the total, were observed for Illinois, Michigan, New Jersey, New York, Ohio, and Pennsylvania. Among these 10 states, Michigan had the highest ratio of 92 percent, and Texas had the lowest ratio of 40 percent (industrial R&D in the manufacturing sector as a percentage of total industrial R&D). Part of this variation is attributable to differences among states in terms of their relative proportions of manufacturing and nonmanufacturing industries. Michigan, for example, is concentrated in motor vehicle manufacturing, and California devotes a great deal of R&D to software development and agricultural research. In Texas, 25 percent of industrial R&D performance took place in its computer and electronic products sector and another 20 percent in mining and extraction (including drilling for petroleum). Other factors, besides the locations of industrial production, may also play a role. For example, industries tend to perform research near universities that conduct the same type of research, enabling them to benefit from local academic resources.

Trends in National R&D by Character of Work

One traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. Admittedly, the traditional categories of basic research, applied research, and development do not always ideally describe the complexity of the relationship between science, technology, and innovation. However, alternative and perhaps more realistic models of the innovation process are probably too complicated to be used in collecting and analyzing comparable and reliable data for policymaking purposes and would not enable time-series analyses. See sidebar, "Choice of Right R&D Taxonomy Is a Historical Concern," later in the chapter. Nonetheless, in spite of these analytical limitations, these categories generally are useful to characterize the relative expected time horizons and types of investments.

The nation spent $47.9 billion on the performance of basic research in 2000, $55.0 billion on applied research and $161.7 billion on development. (See text table 4-1.) These totals are the result of continuous increases over several years. Namely,

Text table 4-11.
R&D performance by sector and R&D as percentage of GSP, for top 10 R&D performing states: 1999

		Top 10 states in R&D performance, by performing sector				Top 10 states in R&D intensity (states with highest R&D/GSP ratio)		
Rank	Total R&D (millions of dollars)	All R&D performers in state	Industry[a]	Universities and colleges[b]	Federal Government	Top 10 states	R&D/GSP (percent)	GSP (billions of dollars)
1	47,965	California	California	California	Maryland	New Mexico	6.43	51.0
2	18,799	Michigan	Michigan	New York	District of Columbia	Michigan	6.10	308.3
3	14,110	New York	New York	Texas	Virginia	Rhode Island	5.07	32.5
4	12,429	Texas	Texas	Massachusetts	California	Massachusetts	4.64	262.6
5	12,190	Massachusetts	New Jersey	Pennsylvania	Alabama	Maryland	4.63	174.7
6	10,695	Pennsylvania	Massachusetts	Maryland	Florida	District of Columbia	4.50	55.8
7	10,536	New Jersey	Pennsylvania	Illinois	Ohio	Washington	3.98	209.3
8	9,719	Illinois	Illinois	North Carolina	Texas	California	3.90	1,229.1
9	8,336	Washington	Washington	Michigan	New Jersey	Delaware	3.87	34.7
10	8,087	Maryland	Ohio	Georgia	New Mexico	Idaho	3.85	34.0

GSP = gross state product

[a]Includes R&D expenditures of federally funded research and development centers (FFRDCs) administered by industry.

[b]Includes total R&D expenditures of FFRDCs administered by academic institutions.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *National Patterns of R&D Resources: 2000 Data Update,* NSF 01-309 (Arlington, VA, March 2001). Available at <http://www.nsf.gov/sbe/srs/nsf01309/start.htm>.

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since 1980 they reflect a 5.5 percent annual increase, in real terms, for basic research; a 3.9 percent increase for applied research; and a 3.8 percent increase for development. As a share of all 2000 R&D performance expenditures, basic research represented 18.1 percent, applied research represented 20.8 percent, and development represented 61.1 percent. These shares have not changed very much over time. For example, in 1980 basic research accounted for 13.9 percent, applied research accounted for 21.7 percent, and development accounted for 64.3 percent.

Basic Research. In terms of support, the Federal Government has always provided the majority of funds used for basic research. (See figure 4-12.) However, its share of funding for basic research as a percentage of all funding has fallen substantially, from 70.5 percent in 1980 to 48.7 percent in 2000. This decline in the Federal share of basic research support does not reflect a decline in the actual amount of Federal support, which, in fact, grew 3.5 percent per year in real terms between 1980 and 2000. Rather, it reflects a growing tendency for the funding of basic research to come from other sectors. From 1980 to 2000, industry's self-reported support for basic research grew at the rate of 10.0 percent per year in real terms.

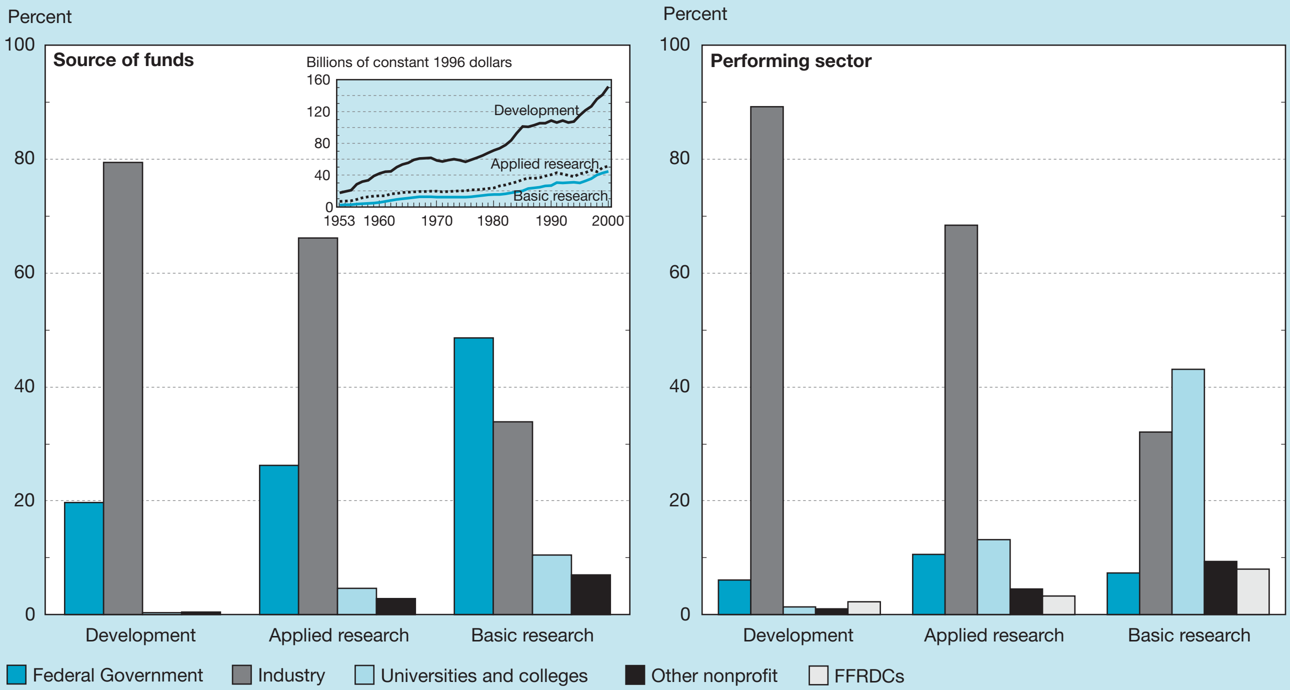
With regard to the performance of basic research in 2000, universities and colleges (excluding FFRDCs) accounted for the largest share with 43.1 percent ($20.7 billion), followed by industry with 32.1 percent ($15.4 billion). Their performance of basic research has undergone, on average, a 4.8 percent real annual increase since 1980. University-administered FFRDCs accounted for another 5.9 percent of total basic research performance in 2000. The dominant role played by universities and colleges in basic research is clearly related to the leading role that universities have in expanding general knowledge of S&E. Along the lines that general knowledge of science is a public good, the Federal Government provided 58.0 percent of the funding for basic research performed by universities and colleges. Non-Federal sources (industry, state and local governments, universities and colleges, and nonprofit organizations) provided the remaining 42.0 percent.

Applied Research. Applied research expenditures total $55.0 billion in 2000 and are performed much more by nonacademic institutions. They have been subject to greater shifts over time because of fluctuations in industrial growth and Federal policy. Applied research experienced a substantial average annual real growth of 7.4 percent between 1980 and 1985, followed by very low growth of 1.1 percent between 1985 and 1994, then rose again to 5.1 percent between 1994 and 2000. Increases in industrial support for applied research explain this recent upturn. Industrial support accounts for 66.1 percent ($36.4 billion) of the 2000 total for applied research and Federal support for 26.3 percent ($14.5 billion).

In the past two decades, Federal support for applied research has been intentionally deemphasized in favor of basic research. Consequently, in 2000 Federal funding for applied research is only 62.0 percent of that for basic research ($14.5 billion versus $23.3 billion, respectively), as reported by research performers.

Most applied research in calendar year 2000 (68.4 percent, or $37.6 billion) was performed by industry. In the same year, most of the nation's nonindustrial applied research was performed by universities and colleges and their administered FFRDCs ($8.7 billion) and the Federal Government ($5.8 billion). For Federal intramural applied research (for which data are organized by fiscal year), 24.7 percent in FY 2000 was

Figure 4-12.
National R&D expenditures, by source of funds, performing sector, and character of work: 2000



FFRDCs = Federally Funded Research and Development Centers

See appendix tables 4-7 through 4-18.

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performed by HHS, 21.8 percent in FY 2000 was performed by DOD, and 11.6 percent was performed by DOC. Total Federal applied research performance has been remarkably level for 34 years, experiencing only a 0.8 percent average annual growth, in real terms, since 1966.

Development. Expenditures on development in calendar year 2000 totaled $161.7 billion, accounting for most of R&D expenditures. Therefore, historical patterns of development expenditures mirror historical patterns of total R&D expenditures. From 1980 to 1985, development grew on average by 7.2 percent per year in real terms as increasingly larger shares of the national R&D effort were directed toward R&D supported by DOD, which tends to be approximately 90 percent development. (See figure 4-13.) Between 1985 and 1994, on the other hand, development in real terms grew at an average annual rate of only 0.7 percent, from $74.5 billion in 1985 to $103.0 billion in 1994. Between 1994 and 2000, annual growth was back up to 5.9 percent in real terms to $161.7 billion in 2000, of which 79.4 percent was supported by industry and 19.7 percent by the Federal Government.

In terms of performance, industry accounted for 89.2 percent ($144.3 billion) of the nation's 2000 development activities, the Federal Government 6.1 percent ($9.8 billion), and all other performers 4.7 percent ($7.6 billion).

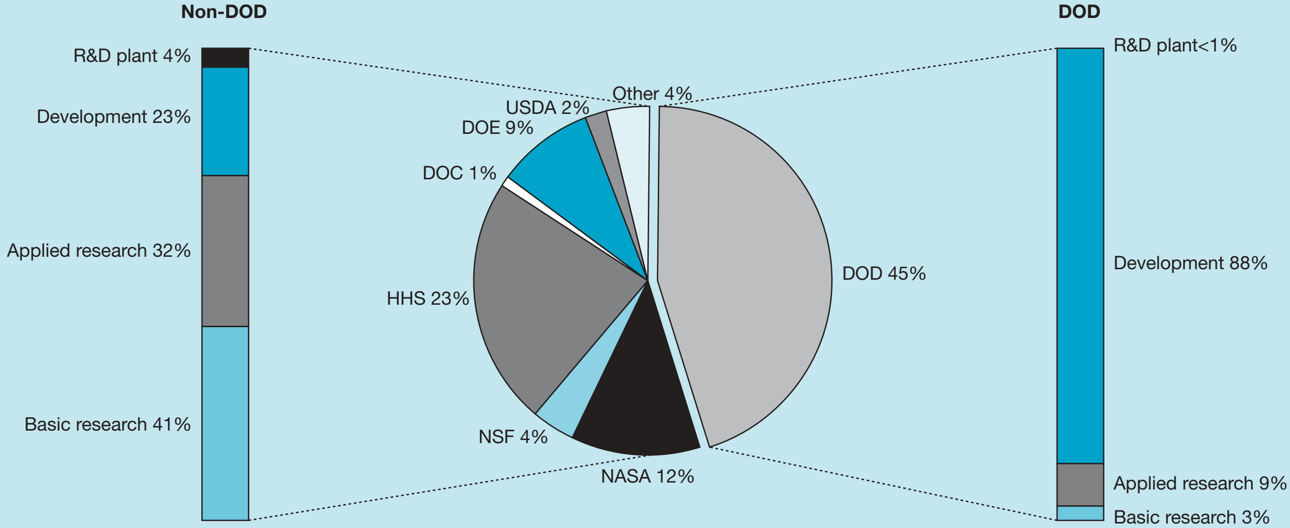
Federal Obligations for Research, by Field

Federal obligations for research alone (excluding development) will total $38.7 billion in FY 2001 by preliminary estimates. Life sciences will receive the largest portion of this funding (47.2 percent, or $18.2 billion), most of which will be provided by HHS. (See figure 4-14.) The next largest field in Federal obligations for research in FY 2001 will be engineering (18.3 percent), followed by physical sciences (11.5 percent), environmental sciences (8.4 percent), and mathematics and computer sciences (6.5 percent). Social sciences, psychology, and all other sciences will account for another 2.6 percent, 1.9 percent, and 3.6 percent, respectively.

In terms of agency contributions to these research efforts, HHS, primarily through NIH, will provide the most (42.8 percent) of all Federal research obligations in FY 2001. The next largest contributor will be NASA (12.2 percent) with substantial funding of research in engineering ($2.2 billion), physical sciences ($0.9 billion), and environmental sciences ($1.1 billion). (See figure 4-14.) DOE will provide 11.7 percent of research funding, primarily in the fields of engineering, physical sciences, and mathematics and computer sciences. DOD will fund a similar amount of research (11.4 percent of the total), primarily in the areas of engineering and mathematics and computer sciences. NSF will provide 8.2 percent of research funding, with between $0.5 and $0.7 billion contributed to each of the following fields: life sciences, engineering, physical sciences, environmental sciences, and mathematics and computer sciences.

Federal obligations for research have grown at different rates for different fields of S&E, reflecting changes in perceived public interest in those fields, changes in the national

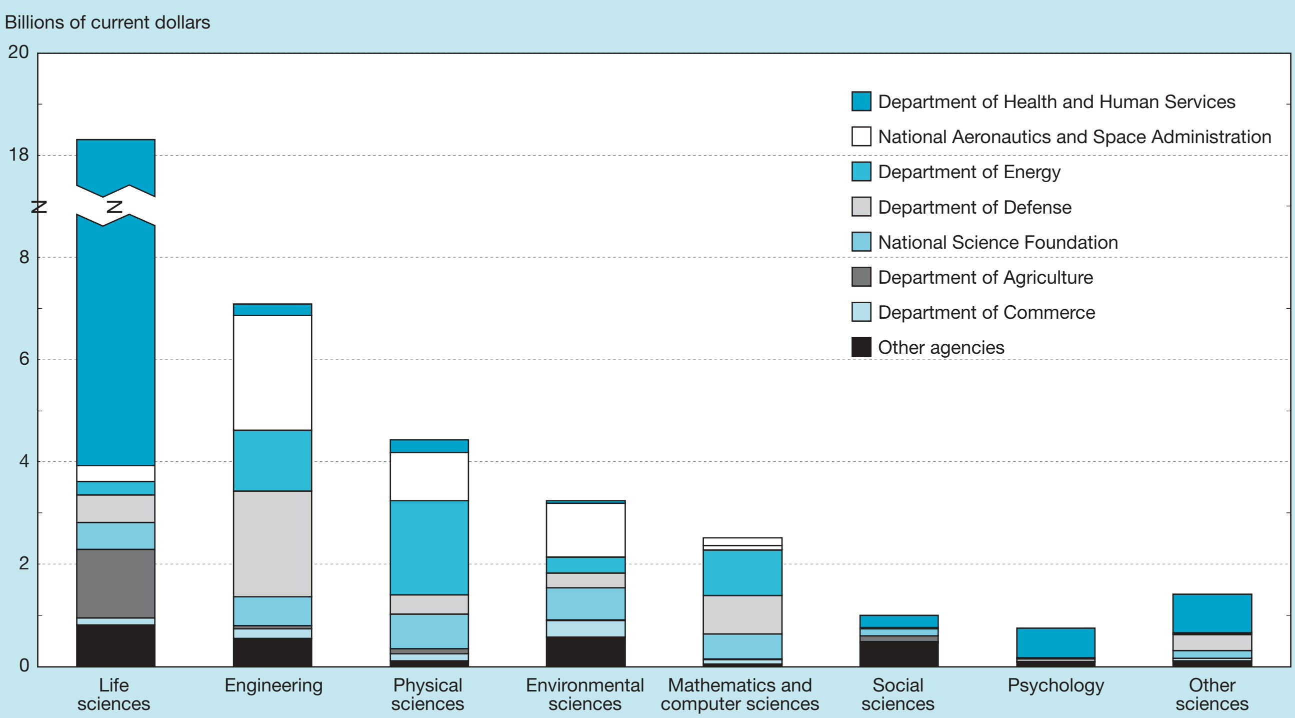
Figure 4-13.
Projected Federal obligations for R&D and R&D plant, by agency and character of work: FY 2001



DOC = Department of Commerce; DOE = Department of Energy; DOD = Department of Defense; HHS = Department of Health and Human Services; NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; USDA = U.S. Department of Agriculture

See appendix table 4-25. *Science & Engineering Indicators – 2002*

Figure 4-14.
Federal obligations for research, by major science and engineering field, and agency: FY 2001



See appendix table 4-27. *Science & Engineering Indicators – 2002* resources (e.g., scientists, equipment, and facilities) that have been built up in those fields over time, as well as differences in scientific opportunities across fields. Based on preliminary estimates for FY 2001, the broad field of mathematics and computer sciences has experienced the highest rate of growth in Federal obligations for research, which was 8.3 percent per year in real terms between 1980 and 2001. Life sciences had the second highest rate with 3.9 percent, followed by psychology with 3.2 percent, environmental sciences with 1.3 percent, engineering with 1.2 percent, and physical sciences with 0.6 percent. Research in the social sciences (including anthropology, economics, political sciences, sociology, and other areas) experienced a slight decline of 0.12 percent.

These trends in Federal support for the above-mentioned broad fields of research, however, may not reflect trends for the smaller fields that they contain. For example, with regard to the broad field of mathematics and computer sciences, Federal support for research in mathematics grew by 3.8 percent per year in real terms between FY 1980 and FY 1999, whereas support for research in computer sciences grew by 10.2 percent.[22] During the same period, within life sciences, support for biological and agricultural research grew by 1.7 percent compared with research support for medical sciences, which grew by 4.6 percent. Within the physical sciences, support for astronomy grew by 1.8 percent, whereas support for chemistry declined by 0.23 percent.

Cross-Sector Field-of-Science Classification Analysis

Federal and academic research expenditures are often classified according to the S&E fields they support. However, it may also be useful to classify all R&D activity by specific S&E fields. Such classification, when applied to historical data, would indicate how R&D efforts in various fields of S&E have grown in economic importance over time. This information is potentially useful for science policy analysis and for planning and priority setting.

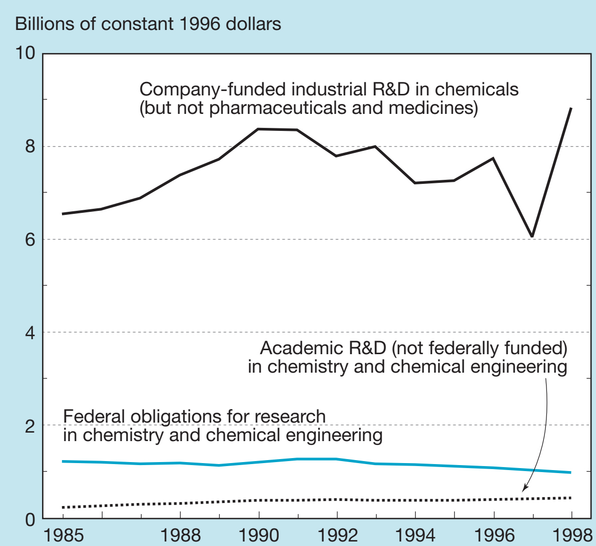
Classification of academic R&D by field of science is provided in detail in chapter 5. At present, the only additional sector for which there exist extensive data by field is the Federal Government. Industrial R&D, which represents three-fourths of all R&D performed in the United States, is not collected by field of study for three reasons:

- ♦ Unlike universities and Federal agencies, most private companies do not have the recordkeeping infrastructure in place to compile such statistics; thus, any efforts on their part to provide this additional information could be significantly burdensome to them.
- ♦ Much of the research by private firms is confidential, and the provision of such information to outsiders might compromise that confidentiality.
- ♦ Much of the R&D carried out by industry is interdisciplinary, especially at the development stage (e.g., the development of a new vehicle would involve mechanical engineering, electrical engineering, and other fields), which in many cases might make the splitting of R&D by field somewhat arbitrary.

Nonetheless, some analysis by field of study, wherever possible, shed light on overall levels of R&D support for general lines of inquiry. In particular, this problem can be circumvented by grouping fields within standard industrial categories, thereby creating categories of R&D that can be associated both with S&E fields and with related industrial categories. We focus in particular in two broad areas, chemistry (nonmedical) and chemical engineering, and life sciences. For ease in data interpretation, all academic and Federal FY data were converted to calendar year data so that they would be comparable to the data pertaining to industry categories (which are collected and provided on a calendar year basis).[23]

R&D in Chemistry (Nonmedical) and Chemical Engineering. In 1998, R&D in the broad area of chemistry and chemical engineering accounted for approximately $10.3 billion (in constant 1996 dollars). Three categories of R&D were identified in this area.[24] (See figure 4-15.) The largest of these categories, by far, is company-funded R&D in industrial chemicals and other chemicals (but not pharmaceuticals and medicines). In real terms (constant 1996 dollars), expendi-

Figure 4-15.
R&D associated primarily with chemistry (nonmedical) and chemical engineering



See appendix table 4-28.

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[22]For these smaller field categories, the latest available data are for FY 1999.

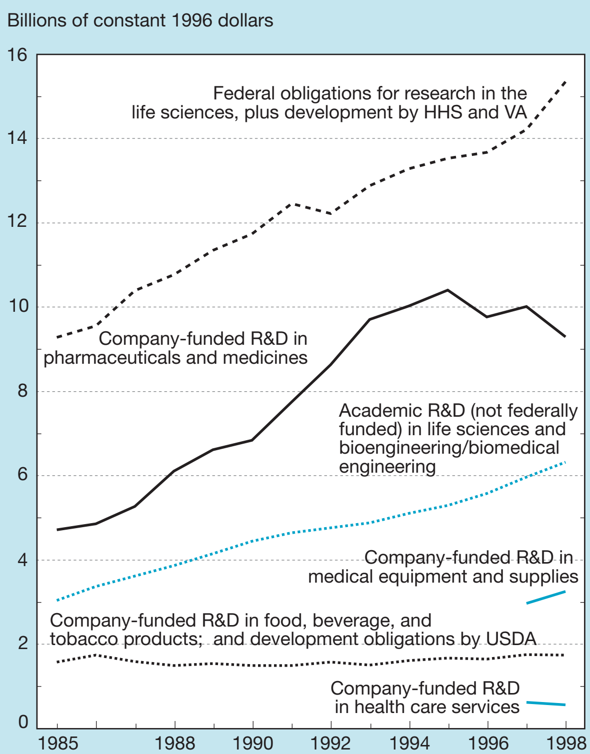
[23]At this writing, the most recent data on academic R&D performance and Federal R&D obligations are for FY 1999. However, the conversion of these numbers from fiscal year to calendar year meant that only data estimates for calendar year 1998 were possible for these figures because estimation of calendar year 1999 data would have required fiscal year 2000 data, which were not available. All dollar amounts in this section are given in real terms (constant 1996 dollars).

[24]These categories exclude chemistry associated with medicine, which was included instead under life sciences.

tures in this category grew from $6.6 billion in 1985 to $8.8 billion in 1998, although the sector has displayed considerable year-to-year fluctuation between 1996 and 1998 (inclusive). The next two categories were much smaller. Federal obligations for research in chemistry and chemical engineering declined between 1985 and 1998, from $1.2 to $980 million (in constant 1996 dollars). Academic R&D (not federally funded) in chemistry and chemical engineering, the smallest category, grew steadily in real terms, from $237 million in 1985 to $444 million in 1998.

R&D in Life Sciences. The broad life sciences field accounted for $36.5 billion of R&D in 1998 (in constant 1996 dollars). R&D in this area is characterized by strong and fairly continuous real growth in its three largest categories. (See figure 4-16.) The largest of these three, Federal obligations for research in the life sciences, plus development expenditures by HHS and the Department of Veterans Affairs, rose from $9.3 billion in 1985 to $15.4 billion in 1998 in constant 1996 dollars. Company-funded R&D in pharmaceuticals and medicines grew dramatically in real terms, from $4.7 billion in 1985 to $10.4 billion in 1995 but then declined to $9.3 billion by 1998. In contrast, academic R&D (not federally funded) in life sciences and bioengineering/biomedical engineering grew continuously, from $3.0 billion in 1985 to $6.3 billion in 1998.

Figure 4-16.
R&D associated primarily with life sciences



HHS = Department of Health and Human Services; USDA = U.S. Department of Agriculture; VA = Department of Veterans Affairs

See appendix table 4-29.

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With regard to food and other traditional products, however, company-funded R&D in food, beverage, and tobacco products, and development expenditures by USDA, show virtually no real R&D growth. That is, as shown in figure 4-16, R&D for this combined subcategory grew only from $1.6 to $1.7 billion between 1985 and 1998. Finally, two new categories of industrial R&D in the life sciences, arising from the new NAICS classification system, are company-funded R&D in health care services and company-funded R&D in medical equipment and supplies. In 1998, the former accounted for $566 million in R&D and the latter for $3.3 billion, in constant 1996 dollars.

Research Alliances: Trends in Industry, Government, and University Collaboration

All major players involved in the creation, diffusion, and commercialization of R&D have experienced changes in how innovation activities are financed, organized, and performed (Jankowski 2001a; Mowery 1998). Well-known risks of conducting scientific research and commercializing its results have been compounded by the increased speed and interdisciplinary nature of technological developments. In this environment, collaborations and alliances, at home or overseas, allow partners to share R&D costs, pool risks, and enjoy access to firm-specific know-how and commercialization resources (Hagerdoon, Link, and Vonortas 2000; Vonortas 1997). In the policy arena, changes in antitrust regulations, intellectual property policy, and technology transfer have fostered a new setting for collaborative research since the early 1980s. (See sidebar, "Major Federal Legislation Related to Cooperative R&D and Technology Transfer.") These changes have paralleled policy and market trends in other advanced economies, contributing to a national and global economy increasingly dependent on knowledge-based competition and networking.

Joint research activities complement other tools to acquire or develop technology, from licensing off-the-shelf technologies to mergers and acquisitions (M&A). Corporate R&D planning increasingly requires a combination of technology exchange (acquisition of external R&D outputs as well as spinoff of noncore technologies) and strategic R&D alliances to excel in innovation and market performance (Arora, Fosfuri, and Gambardella 2000).[25] Even local and Federal Government agencies have developed technology strategies to maximize regional competitive advantage and national benefits. Universities also have adjusted to this new environment by increasing funding links, technology transfer, and collaborative research activities with industry and Federal agencies over the last two decades.

At the same time, collaborative networks are not without risks. Unintended transfer of proprietary technology is always a concern for businesses. Cultural differences among differ-

[25]M&A activity and international R&D investments are covered in a separate section below.